Mid-IR and Near-IR *in situ* instrument needs

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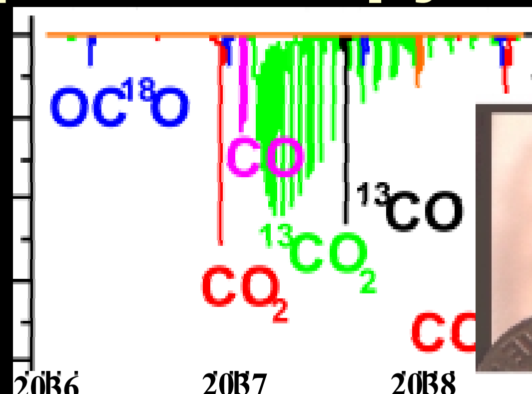
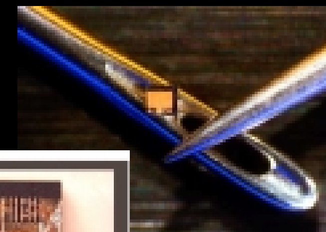
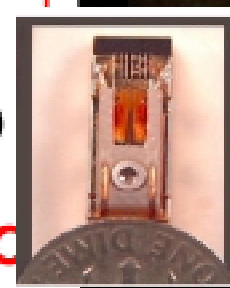
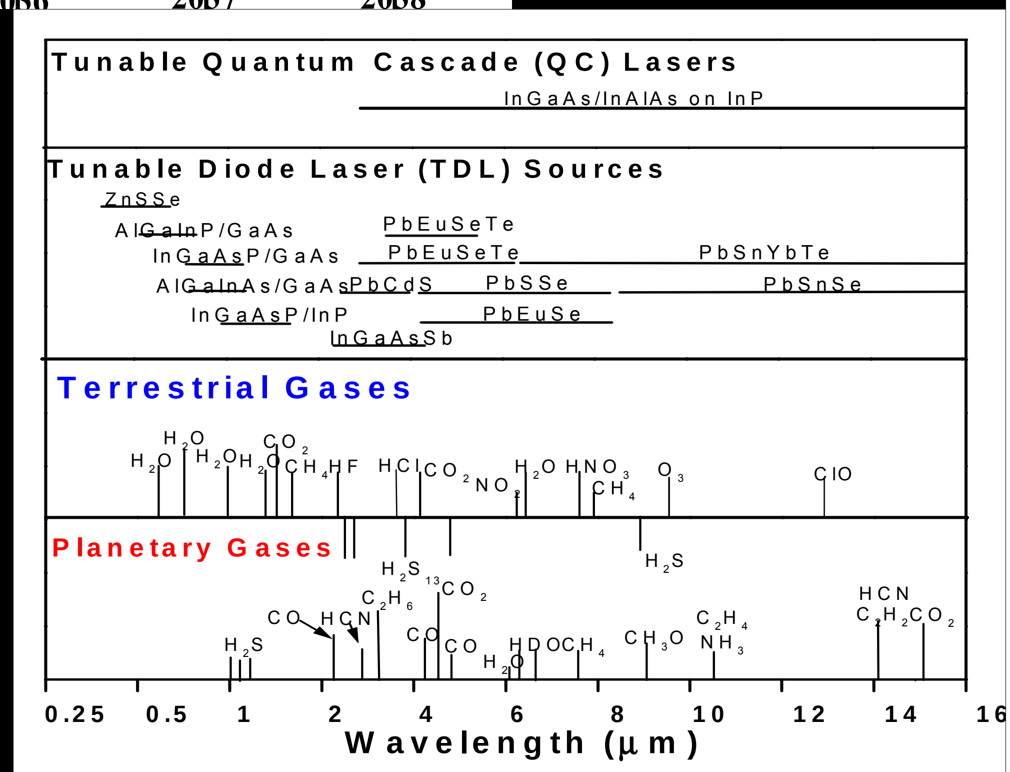
Laser Absorption Spectroscopy

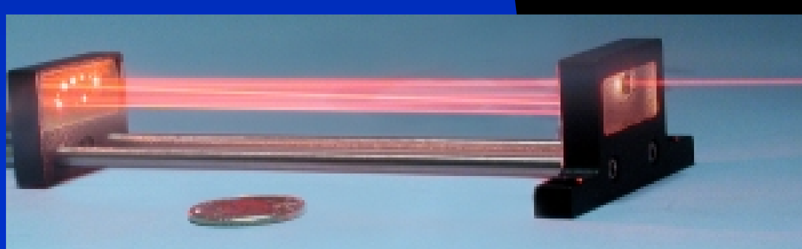
- Narrowband (0.0005 cm^{-1}) tunable diode lasers (TDL) and Quantum-cascade (QC) lasers matched to absorption line(s) (1.3 – 10 µm) of gases of interest.
- Numerous TDL-based absorption instruments have been flown on balloon & aircraft missions.
- For Earth, well-suited to certain target gases: H_2O, N_2O, CH_4, CO, HCl, NO_2, HNO_3, H_2CO, isotopes of H_2O, isotopes of CO_2.
- Sensitivity – sub-parts-per-billion.











Overview of Aircraft, Balloon, and Ground-based instruments

~ 30 TDL/QC laser spectrometers currently measuring Earth atmospheric gases

Laser Sources:

- Near-IR TDLs (InGaAsP) operate cw at room temp (TE cooler)
- Traditional Mid-IR (Pb-salt) TDLs operate at LN_2 temps
- Mid-IR QC lasers (InGaAs) operate cw at LN_2, pulsed at room temp

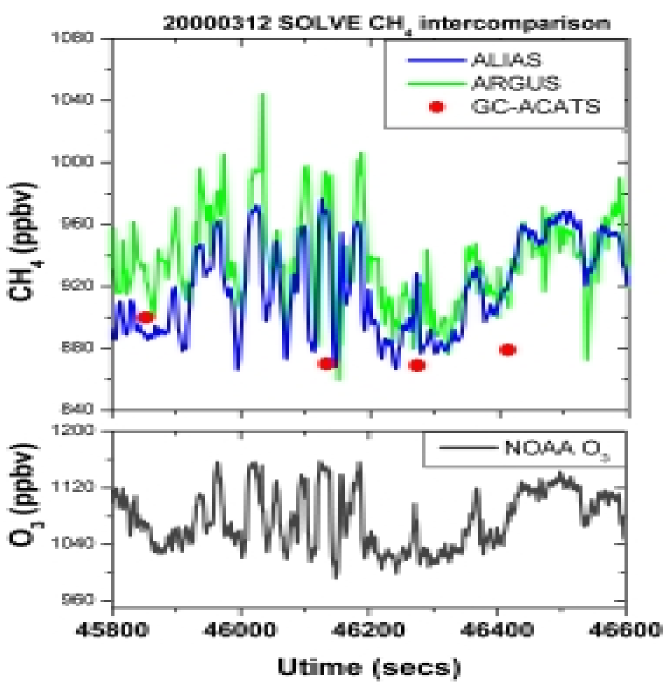
Measurement Geometry:

- Open path (large ΔT) or flowing cell (T-regulated)

Technique:

- Line-locked: higher duty cycle (precision), poor line information
- Tunable: full spectral line information, lower duty cycle (precision) [2f or sweep integration]
- LAS and CRDS

Unified N_2O: GCMS has better absolute accuracy, but laser spectrometers offer superior sensitivity, specificity, precision, and response time.



Mid-IR Aircraft, Balloon, and Ground-based Spectrometers

Instrument	Path	Technique	PI	Institution	Platform	Gas	Line (cm^{-1})	Calibration	Precision 1 σ	Accuracy
ALIAS	Flowing Herriott cell 80 m	Tunable TDL and QC	Chris Webster	JPL	ER-2	N_2O CH_4 CO CO_2 HCl NO_2	2232 1256 2169 2233 2926 1603	Pre-flight + in-flight CO_2 Pre-flight Pre-flight In-flight CH_4 Pre-flight	0.6% in 1.3 sec 0.3% in 1.3 sec 1% in 1.3 sec (trop) N/A 1% 5%	± 1.8% ± 3% ± 3% N/A 3% 5%
ALIAS-II	Open path Herriott cell 64 m	Tunable	Chris Webster	JPL	Balloon	N_2O CH_4 HCl	2237.7 2927.1 2925.9	Pre-flight Pre-flight In-flight CH_4	3% 3% 10%	± 5% ± 5% ± 10%
ALIS	Flowing Herriott cell 2.8 m	Tunable QC	Chris Webster	JPL	WB-57F	$^{13}CO_2$ CO_2	2303	In flight	0.1% for line ratio in 1.3 sec	Isotopic ratio
ARGUS	Flowing Herriott cell	Tunable	Max Loewenstein, Hansjurg Jost	NASA Ames	ER-2 Balloon	N_2O CH_4	2206 3028	In-flight	1.5% in 2 sec	3.5% in 2 sec
ATLAS	Flowing White cell	Line-locked	Max Loewenstein, Jim Podolske	NASA Ames	ER-2	N_2O	2232	In-flight	about 0.1%	1% 1 σ
BLISS	Open path 0.3-1 km (Lowered retro)	Tunable	Chris Webster	JPL	Balloon	HCl N_2O CH_4 CO NO_2 NO HNO_3 O_3	2926 1252 1343 2169 1603 1900 1333 1063	Spectroscopic line parameters	1-5% in 30 sec	2-15%
DACOM I	Flowing cell 36 m Herriott Cell	Line-locked	Glen Sachse	NASA LaRC	DC-8	CO CH_4 N_2O	2116 ± 3018 ± 2212±	In-flight NOAA/CMDL Standard	1% in 1 sec 0.1% in 1 sec 0.1% in 1 sec	2% 1% 1%
DACOM II	Flowing cell 36 m Herriott Cell	Line-locked	Glen Sachse	NASA LaRC	P-3	CO CH_4	2116 ± 3018 ±	In-flight NOAA/CMDL Standard	1% in 1 sec 0.1% in 1 sec	2% 1%
FLAIR	Flowing White cell 126 m	Line-locked and 2f	G.W. Harris	York Univ. Canada, MPI Germany.	F-116	H_2O_2 NO_2 HCHO CO	1245 1629 1730 2073	Pre-flight?	Xx% in 1 minute?	??????
NERC IFMA spectrometer	Open path	Tunable	Howieson, Duxbury, Swann, Gardiner, Jones	Strathclyde U., NPL, & Cambridge U., UK	Balloon 5-30 km	CH_4	6097	??????	??????	??????

Mid-IR Aircraft, Balloon, and Ground-based Spectrometers (contd.)

Instrument	Path	Technique	PI	Institution	Platform	Gas	Line (cm^{-1})	Calibration	Precision 1 σ	Accuracy
NERC COSMAS NIR	Flowing cell or open path	Tunable	Walker, Langford, Duxbury, Brassington	Strathclyde U., & Imperial College, UK	Ground or aircraft	C2H6 CH_4, CH3OH H2CO	6097 1730		TBD	TBD
NCAR TDLAS	??????	??????	Bill Mankin and Mike Coffey	NCAR	WB-57 C-130	CO, N2O	??????	??????	3% in 30 sec	5%
NOAA TDLAS	??????	??????	Eric Richards, Ken Kelly	NOAA	WB-57	CH_4	??????	??????	??????	5%
OPTIMA	Open path Herriott cell	Rapid Scan HF 2f	Jim Podolske	NASA ARC	DC-8	HNO_3	1721-1723	Absolute spectral parameters	TBD	TBD
Cavity Ringdown Laser Spectrometer	??????	??????	Jim Anderson	Harvard University	WB-57F	CH_4	1333	Pre-flight + in-flight gas addition	0.3% for 10 sec	1%
Eddy – Correlation TDLAS	Flowing cell (Herriott)	Dewar based, tunable system with line locking	Peter Werle and Robert Korman	Fraunhofer Institute, Germany	Ground	CH_4	1290	Calibration Gas from cylinder + dilution system (every 30 min)	0.5% for 0.1 sec	??????
TDLAS for formaldyhyde	Flowing Astigmatic Herriott cell	Tunable, 2f + sweep integration	Alan Fried	NCAR	Ground, DC-8, Electra, WP3, C-130	HCHO	2831.6417	In flight calibration and zeroing	20 – 50 pptv in minute (1σ), 150 – 400 pptv in 1 second	6 – 10 %
Mid infrared TDLAS	Flowing cell (White)	Tunable system with line locking	Peter Werle et al.	Fraunhofer Institut, Germany	Ground	NO_2 CH_4 HCOH	1600 3076 2800	Permeation System Calibration Gas Permeation System	0.3% for 1.5 sec 0.08% for 25 sec 0.3% for 1.5sec 0.08% for 25 sec 2% for 0.06 sec 0.5% for 1 sec 0.1% for 20 sec 1.4% for 1.5 sec 0.3% for 40 sec	??????
TDLAS	??????	??????	Harold Schiff	??????	Electra	NO_2 HNO_3	??????	??????	??????	??????
TDLAS	Flowing White cell	??????	Don Hastie and Miller	??????	Balloon	NO, NO2	??????	??????	??????	??????
TILDAS-36 TILDAS-200	Flowing path	Tunable, direct absorption	Mark Zahniser	Aerodyne Research Inc	Ground Flux Tower Mobile van	CH_4 N_2O HNO_3 NO_2 NO SO_2 NH_3	3017 2240 1722 1600 1900 1370 1065	Cal gas Cal gas HITRAN line parameters JPL lines	0.1% in 1 sec 0.1% in 1 sec 500 ppt 1 sec 200 ppt 1 sec 500 ppt 1 sec 500 ppt 1 sec 100 ppt 1 ses	±5% ±5% ±20% ±20% ±20% ±20% ±20%

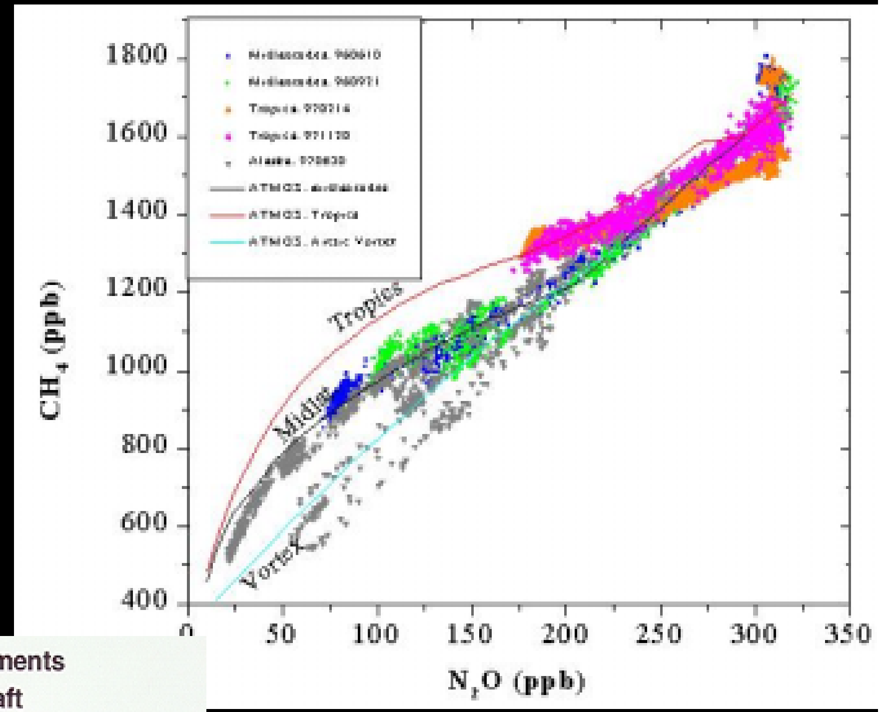
Near-IR Aircraft and Balloon Spectrometers

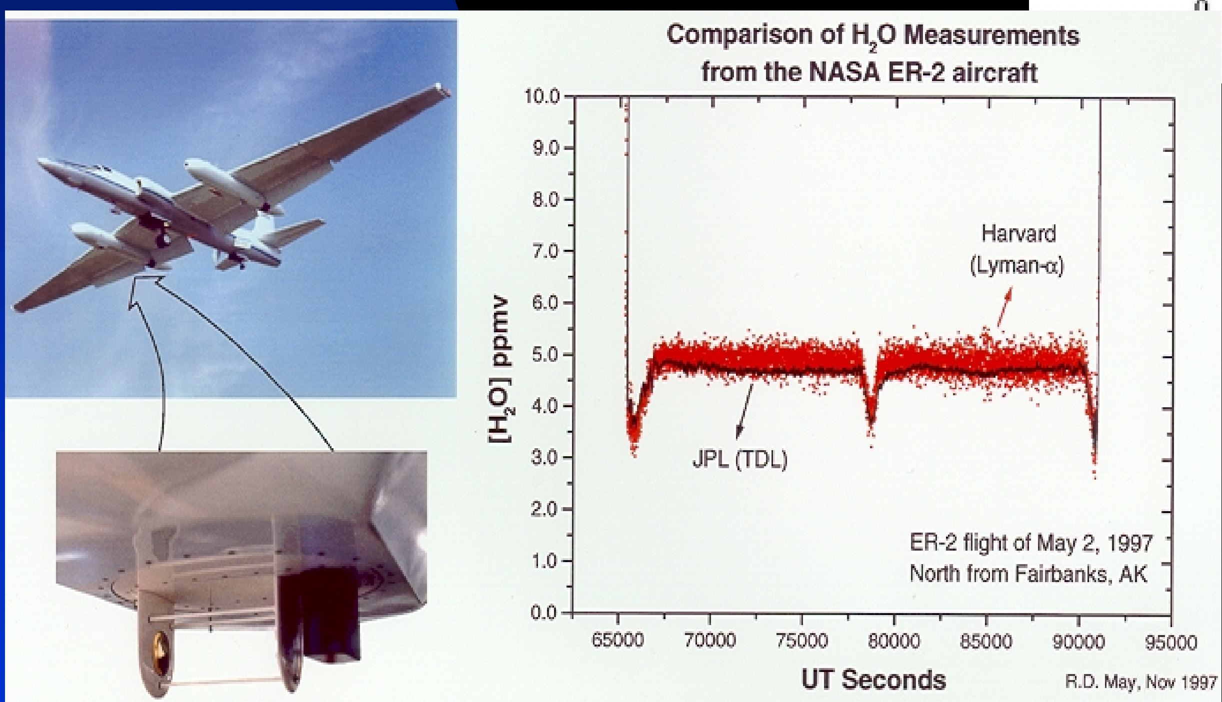
Instrument	Path	Technique	PI	Institution	Platform	Gas	Line (cm^{-1})	Calibration	Precision 1 σ	Accuracy
DLH	30m Open path	Line locked	Glenn Sachse Jim Podolske	NASA LaRC/Ames	DC-8	H_2O	7118 and 7122	Pre and post mission	Greater of 0.1 ppmv or 2% conc. in 50 msec	10%
JLH-ER-2	Open path	Tunable	Bob Herman	JPL	ER-2	H_2O	7294.1	Pre-flight	1-2% in 1 sec	± 5%
JLH-WB57	Open path	Tunable	Bob Herman	JPL	WB57	H_2O	7299.4	Pre-flight	1-2% in 1 sec	± 5%
JLH-DC-8	Open path	Tunable	Bob Herman	JPL	DC-8	H_2O	7306.8	Pre-flight	??????	??????
NCAR Water	Open path	Tunable	Bruce Gandrud	NCAR	C-130	H_2O	??????	??????	??????	??????
Physical Sciences LH	Open path	Tunable, Balanced ratiometric detection	David Sonnenfroh	Physical Sciences, Inc.	P3 B	H_2O	7181.2	??????	??????	??????
SDLA	Open path	Tunable	Georges Durry	CNRS, France	Balloon	CH_4, H_2O	6046.9, 7181.1(strat) 7188.3(trop) 7185.6(trop) 7183(trop)	Pre-flight	??????	5%-10%
SWS LH	Open path	Tunable	Joel Silver, DC Hovde	Southwest Sciences, Inc	KC-135	H_2O	7612	??????	??????	??????
Near infrared TDLAS	Flowing cell (Herriott)	Peltier cooled, tunable system with line locking	Peter Werle et al.	Fraunhofer Institut, Germany	Ground	CO_2	4990	Calibration Gas	0.08% for 1 sec	??????
TOTCAP Water	Flowing path	Tunable	Linnea Avallone	LASP/ U.Colorado	DC-8, commercial	H_2O	7306.75	Pre-flight and post flight	1-2% in 1 sec	5%-10%

•Increasingly-sophisticated scientific questions addressed by *in situ* payloads (aircraft, balloon) has increased demand for higher precision, higher accuracy measurements of tracers, water.

(e.g. CO_2 vs. N_2O tracer correlations)

•Aircraft platforms have duplication with differing techniques for continuous intercomparison.

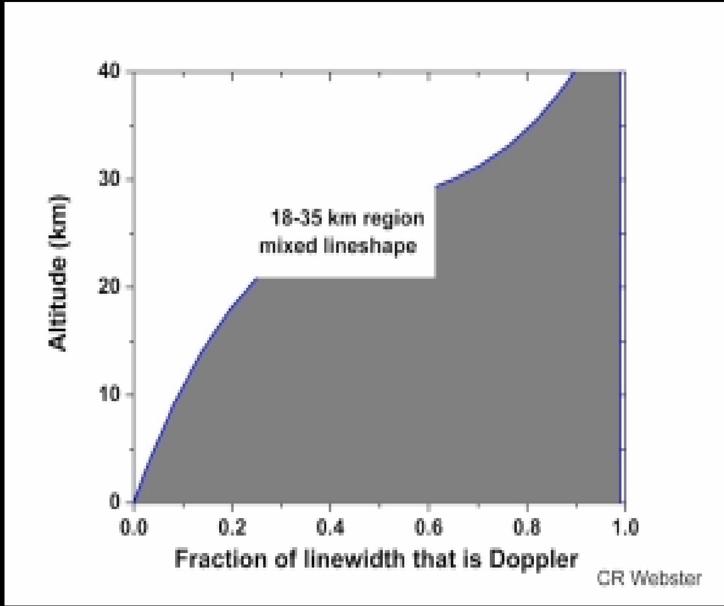




IR Vibration-rotation Lineshapes

Linestrength is integrated absorption coefficient

$$S = \int k(\tilde{v})\,d(\tilde{v}) \qquad\qquad k(\tilde{v}) = S g(\tilde{v} - \tilde{v}_o)$$



Natural linewidths ~tens of kHz (msec lifetimes)

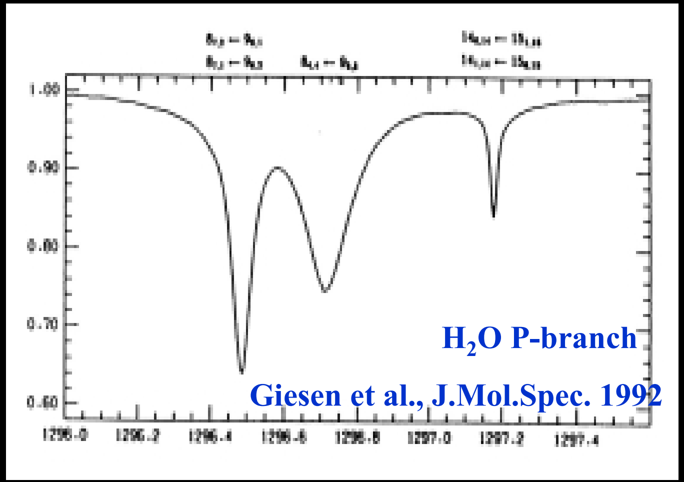
•**Doppler Line Broadening** $\gamma_D \ directly \propto T^{1/2}$

= 3.581 x 10^{-7} $v_0(T/M)^{1/2}$ cm^{-1} (~ tens of MHz)

$$k(\tilde{v}) = \left(S/\gamma_D\right)\left(\ln 2/\pi\right)^{1/2} \exp\left[-(\tilde{v}-\tilde{v}_o)\ln 2/\gamma_{D^2}\right]$$

•**Collisional Line Broadening** $\gamma_L \propto 1/T^{1/2}$

$$g_L(\tilde{v}-\tilde{v}_o) = \frac{\left(\gamma_L/\pi\right)}{(\tilde{v}-\tilde{v}_o)^2 + \gamma_L^2} \qquad\qquad \gamma_L = \left[\gamma_A\left(\frac{P_a}{P_0}\right) + \gamma_B\left(\frac{P_b}{P_0}\right)\right]\left(\frac{T_o}{T}\right)^s$$



SBC > FBC SBC=0.08 cm^{-1} atm^{-1}(CH_4) to 1.0 (HNO_3)

FBC up to 0.15 cm^{-1} atm^{-1} for N_2 on H_2O

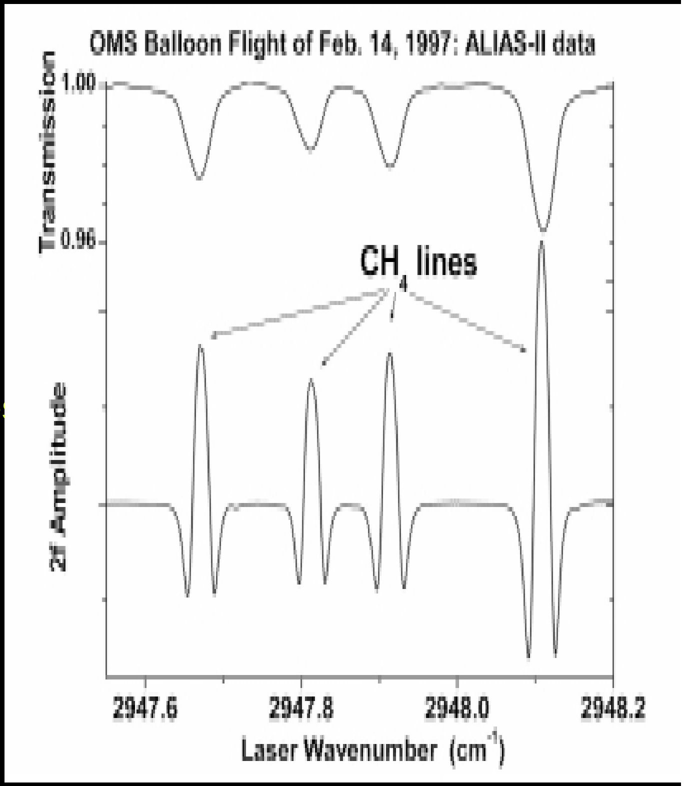
Width usually varies smoothly with m.

Mixed Lineshapes and the Voigt Profile

•**Pressure-broadening coefficients of H_2O known to depend on rotational quantum numbers of vibe-rot transitions involved, but not always temp dependence (0.6-0.8) [Varanasi]**

Spectroscopic needs for *in situ* laser spectrometers

- Spectroscopic needs are fundamentally different from those of remote sensing spectrometers.
- Care about behavior of carefully-chosen, isolated, single lines:
  - absolute line strength (precision)
  - E'' (temperature change or extrapolation susceptibility)
  - broadening coefficient and temp dependence (extrapolation linearity)
  - temperature dependence of line shape to avoid surprises in modulation methods
  - interferences (esp. for weak lines of CH_4, H_2O, CO_2, O_3 etc.)
  - Pressure-shifts for instruments line-locked to fixed reference cell pressure.
- For known spectroscopic parameters, absorption method is self-calibrating through Beer's Law.
- Need path length, laser line-width (Doppler cells), pressure, temperature, direct absorption spectrum.



Calibration methods for *in situ* laser spectrometers

REACTIVE GASES

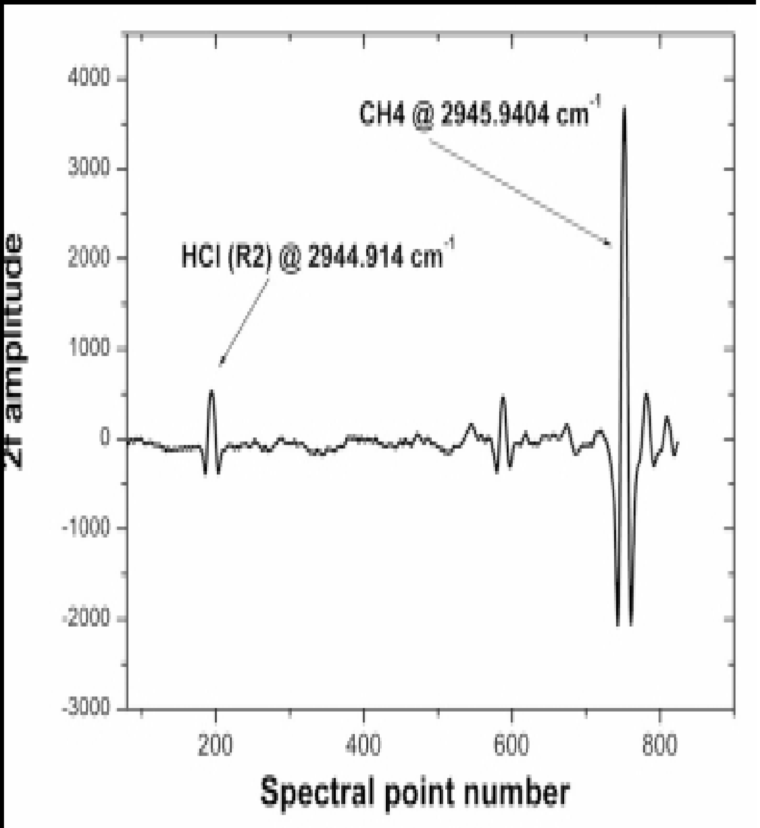
• Chemically, thermally, or photochemically unstable in reference gas cells

• Pre-flight calibration difficult (especially at low Temps and low mixing ratios:

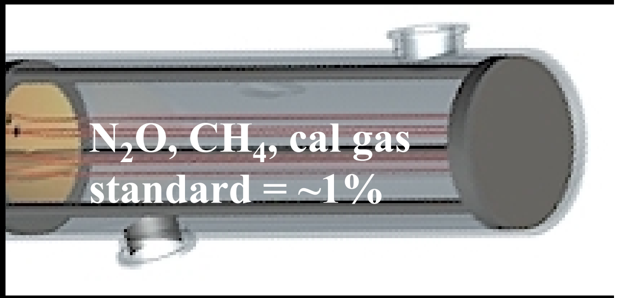
- **sticky (polar) molecules: HNO_3, H_2O, HCl**
- **NO, NO_2 permeation tubes**
- **H_2CO (Alan Fried) uses Henry's Law Calibration System HLCS**
- **H_2O laser spectrometers use chilled-mirror frost-point hygrometer**

• **Rely on** spectroscopic line parameters that limit measurement uncertainty to ~5-10%

• Use adjacent line normalization where possible (e.g. CH_4 for HCl)

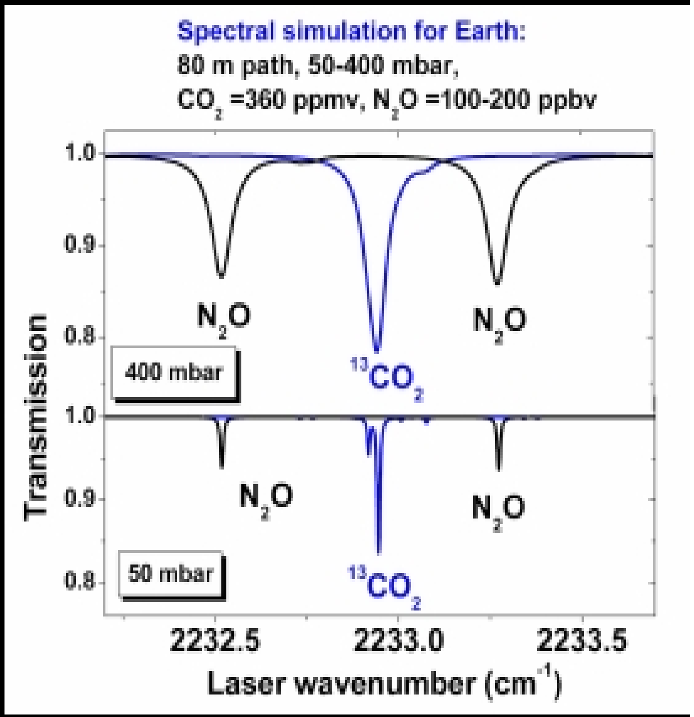


Calibration methods for *in situ* laser spectrometers (contd.)



STABLE GASES

- **Pre-flight calibration using gas standards (~1%)**
  - Referenced to NIST or CMDL standards
  - Easy to map pressure dependence
  - Very difficult to map temp dependence
- **In-flight switching to reference gas cells**
  - Need to be same pressure and temp as sampled atmosphere
- **In-flight calibration using reference atmospheric gas lines such as CO_2**
  - Even seasonal cycle variation in CO_2 is only ±1.4%
  - But still limited by pressure broadening parameters



Measurements of Atmospheric Tracers N_2O, CH_4, CO

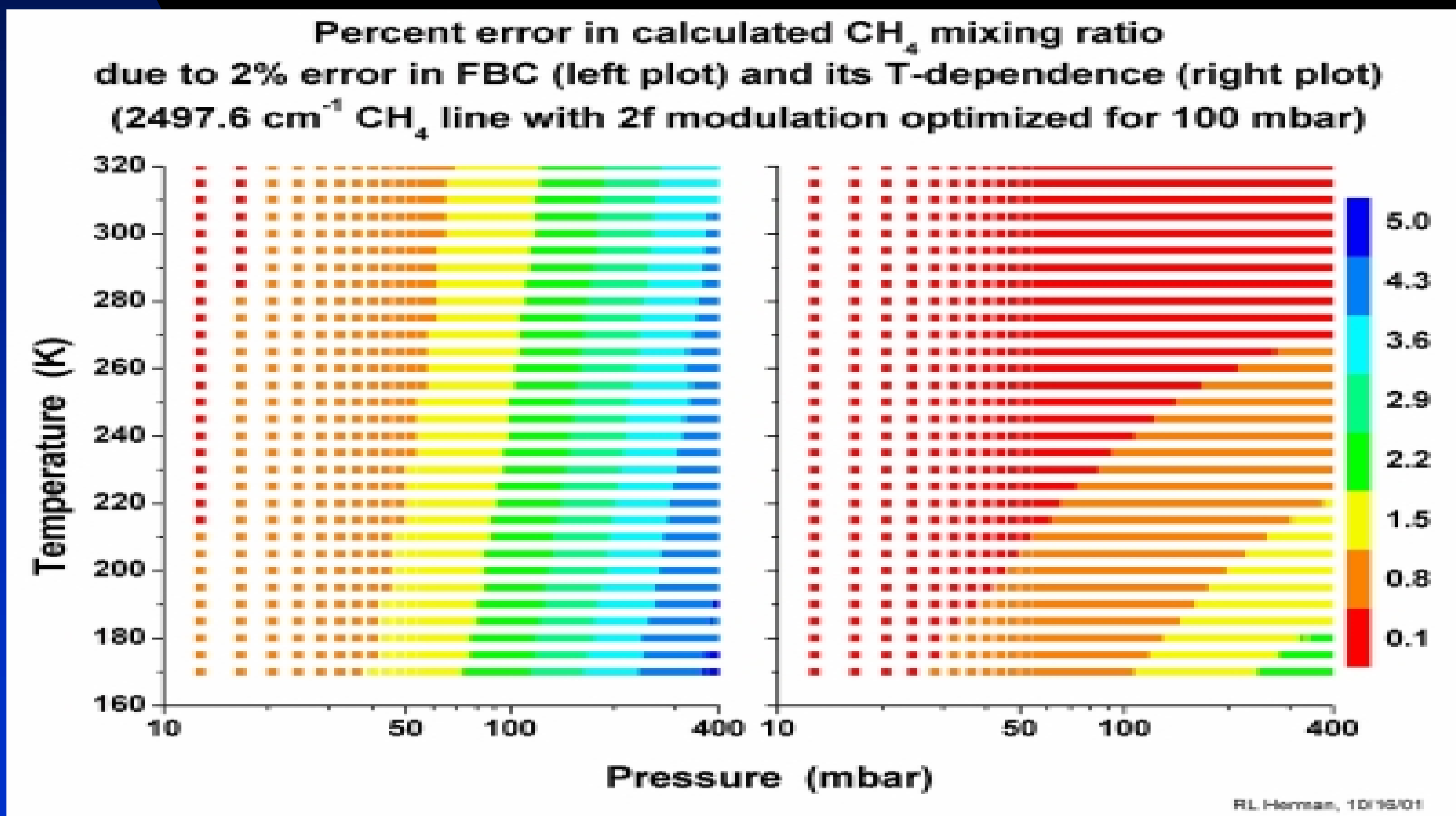
	BAND	UNCERTAINTY		
		Line strengths	FBC	
Strong N_2O bands:				
~4.5 µm (2200 cm^{-1})	ν_3	3%	4%	smooth FBC, S, n, with m: (Fukabori, Varanasi)
~7.7 µm (1300 cm^{-1})	ν_1	3%	4%	
Strong CH_4 bands:				
~3.3 µm (3000 cm^{-1})	ν_3	1-2%	2-5%	some differences, line mixing (Fukabori)
~7.7 µm (1300 cm^{-1})	ν_4	2-5%	2-5%	
~2.3 µm (4350 cm^{-1})	$\nu_3 + \nu_4$	2-5%	2-5%	
Strong CO bands:				
~4.8 µm (2100 cm^{-1})	fund.	2-5%	5-10%	series var. of n 0.6-0.8 with m (Varanasi)

[~2.4 µm band (near-IR) too weak for stratosphere]

Measurements of Atmospheric Tracers N_2O, CH_4, CO (contd.)

<u>For typical aircraft data altitudes (50-300 mbar)</u>

- 2% error in FBC results in ~2% error in final mixing ratio
- 2% error in n results in ~1% error in final mixing ratio



Atmospheric Measurements of H_2O

Minimum-detectable mixing ratio for 10 meter path length and 2 x 10^{-5} absorptance:

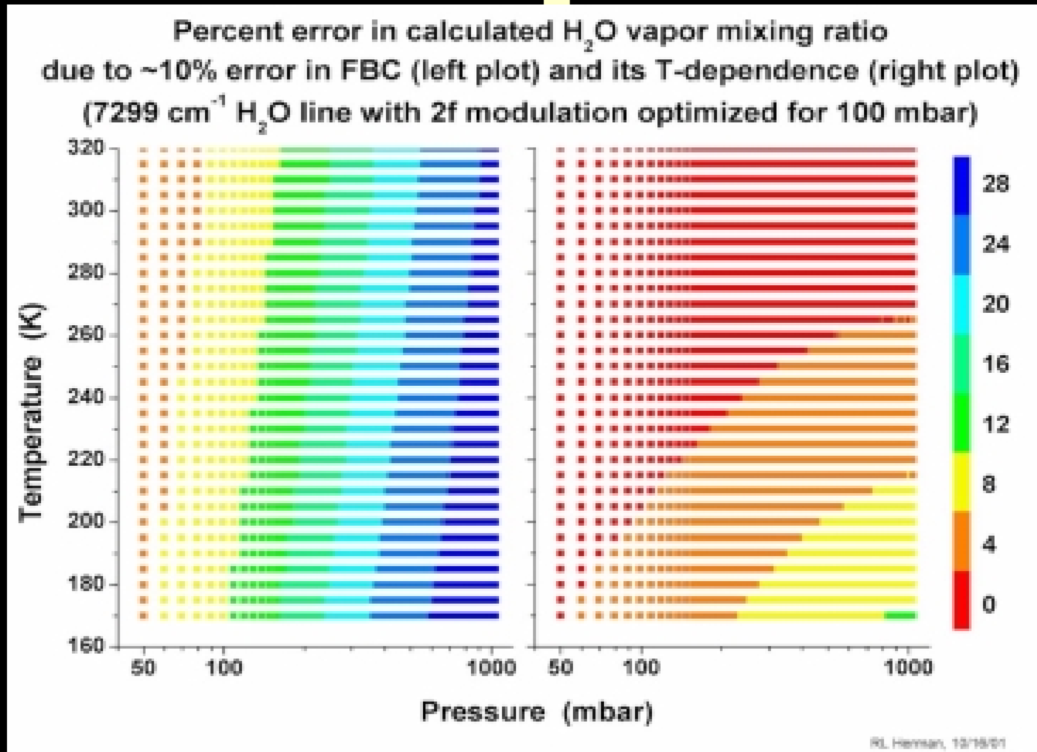
- **Mid-IR is 20 times stronger than near-IR at 1.37 µm**
  - **30 parts-per-billion at 1.37 µm (in 1 sec)**
  - **1.5 parts-per-billion at 5.9 µm**

- **Near-IR TDLs available at room (TE cooler) temperatures, and InGaAs detectors are excellent.**

- **Mid-IR QC lasers will eventually dominate and offer much shorter pathlengths, smaller instruments.**

Near-IR Measurements of H_2O

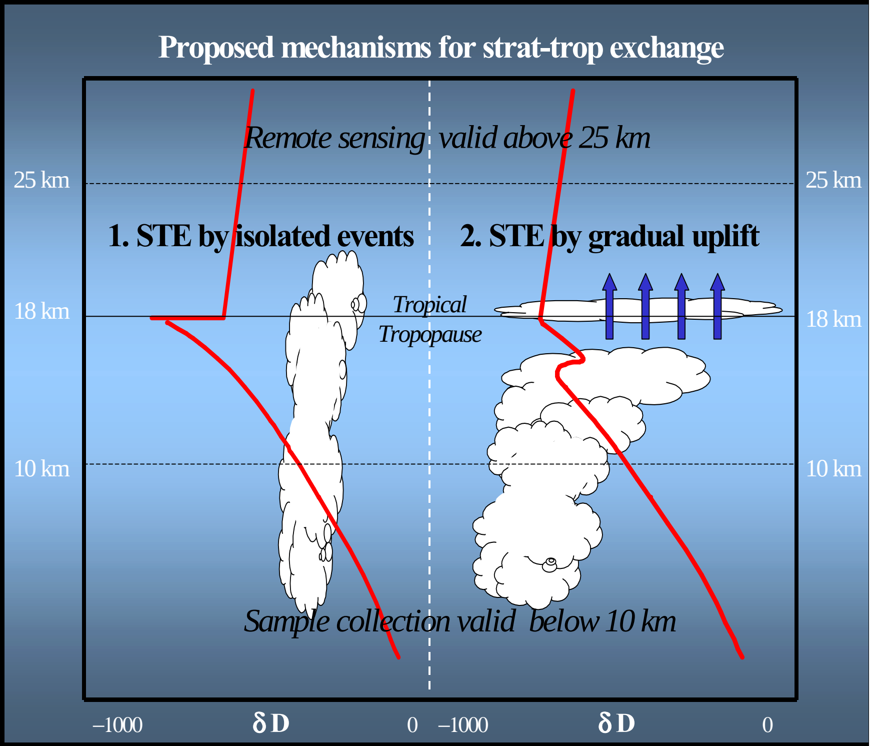
- Unlike other gases, H_2O mixing ratios span 4 orders of magnitude from trop to strat.
- Usually calibrate with chilled-mirror frost-point hygrometer at room temp.
- For diff temperatures, extrapolation is necessary.
- Accuracy in FBC (esp.) and its' T dep is critical.



Instrument (PI)	Line	intensity S	FBC	SBC	E"	n	reported	reported	change	change
	cm-1	cm-1/molec.cm-2	cm-1/atm	cm-1/atm	cm-1		inten. Err	FBC err	rel to Toth	rel to Toth
		(296K)	(296 K)	(296 K)					intensity	FBC
DLH (Sachse)	7139.107	1.20E-20	0.0935	0.504	325.348	0.69	2-5%	5-10%		
PSI (Sonnenfroh)	7182.995	5.30E-21	0.098	0.488	142.279	0.76	2-5%	5-10%		
JLH ER-2 (Herman)	7294.1360	1.900E-20	0.0985	0.433	23.7940	0.78	2-5%	5-10%	24%	-16%
JLH WB-57F (Herman)	7299.4490	1.300E-20	0.1039	0.443	42.3720	0.68	2-5%	ave or est	34%	-11%
JLH DC-8 (Herman)	7306.7360	2.000E-20	0.0973	0.490	79.4960	0.72	2-5%	5-10%	10%	13%
C-130 (Gandrud)										
TOTCAP (Avallone)										
SW Sciences	7612.0000									

Measurements of Water Isotopes H_2O, HDO, $H_2{}^{18}O$, $H_2{}^{17}O$

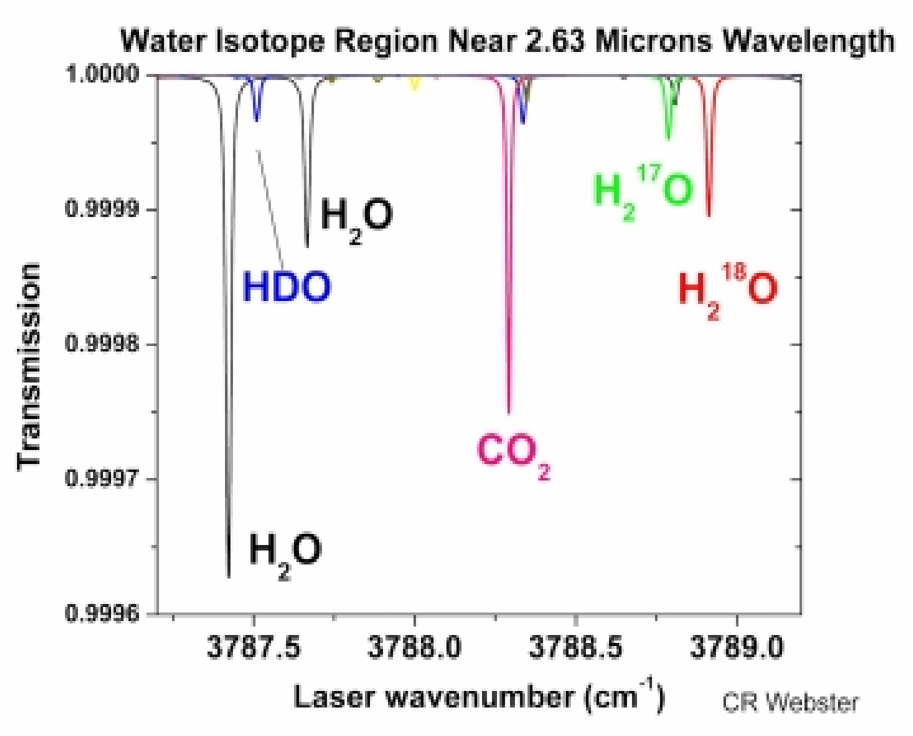
- Determine the processes that regulate upper tropospheric (UT) water vapor, and its' transport into the lower stratosphere (LS).
- Does Strat-Trop Exchange occur through isolated deep convection in the tropics, or gradual uplift of high cirrus or ice sublimation?
- HDO preferentially partitioned into the condensed phase: HDO/H_2O decreases rapidly to top of convective system.
- Delta-D (HDO) changes by large amount (tens of %).
- If adjacent isotopic lines used, precision more important than accuracy.

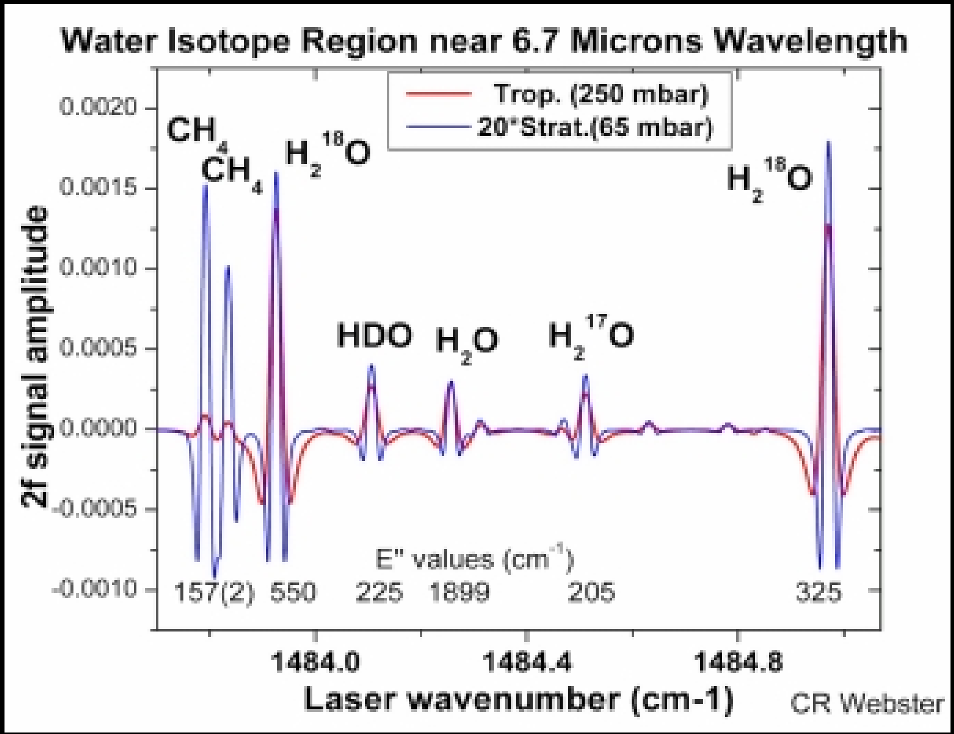


Near-IR and Mid-IR Spectroscopy of Water Isotopes H_2O, HDO, $H_2{}^{18}O$, $H_2{}^{17}O$

Near-IR 2.63 μm | HDO linestrength→ x 2 | Mid-IR 6.7 μm

- **Near-IR lines weaker than Mid-IR, and have stronger interferences from CO_2, other gases**
- **Unlike Mid-IR, Near-IR offers CO_2 normalization**





Mid-IR Measurements of Water Isotopes H_2O, HDO, $H_2{}^{18}O$, $H_2{}^{17}O$

- Region first identified by Rinsland *et al.* 1984 balloon measurements of HDO.
- ATMOS studied lower stratosphere.
- BLISS made first *in situ* TDL measurements in 1989.
- WISP developed for WB57-F, but only flown in test flight with no lasers.
- Community awaits *in situ* measurements near tropopause region at high spatial resolution: uncertainty in measured T ~1% at night.

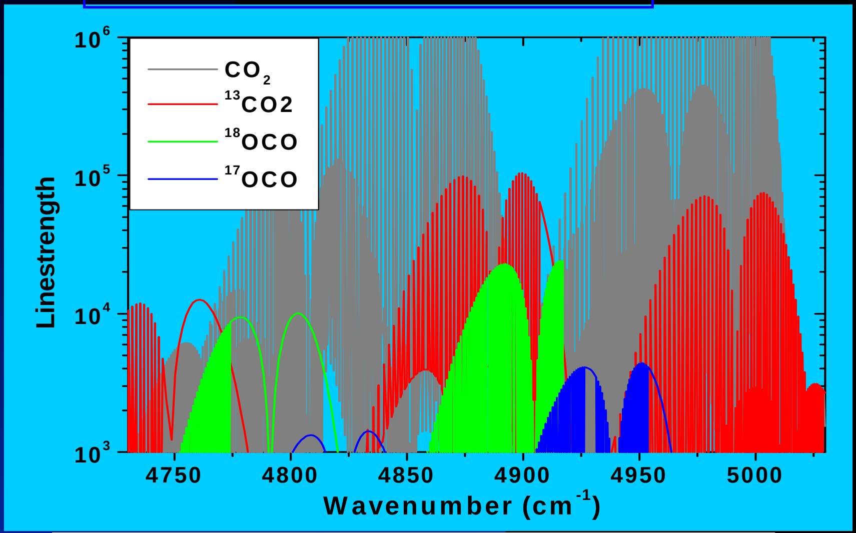
Water Isotope Ratio Measurement Error from Temp Uncertainty of 2 Degrees							
				Water mixing-ratio (ppmv)	**5**	**50**	**200**
				CH4 mixing-ratio (ppmv)	**0.8**	**1.0**	**1.5**
				Atmospheric Temp (K)	**210 K**	**198 K**	**245 K**
				Atmospheric Pressure (mbar)	**60 mbar**	**100 mbar**	**300 mbar**
					Error % from +2 deg error in Temp		
Species	**ν (cm^{-1})**	**S (296 K)**	**E” (cm^{-1})**	**n (cm^{-1})**			
CH4	1483.79230	3.65E-22	157	0.75	-0.6		
CH4	1483.83448	2.29E-22	157	0.75			
H218O	1483.92606	8.39E-23	550	0.49	+0.5	+0.6	+0.4
HDO	1484.10644	2.32E-23	226	0.74	<0.1	<0.1	<0.1
H2O	1484.25726	1.78E-23	1899	0.50	Too weak		
H217O	1484.51094	1.97E-23	205	0.59	<0.1	-0.1	-0.4
H218O	1485.13361	6.25E-23	1907	0.78	+0.5	+0.6	+0.5
(HDO/H217O)					<1 per mil	<1 per mil	4 per mil

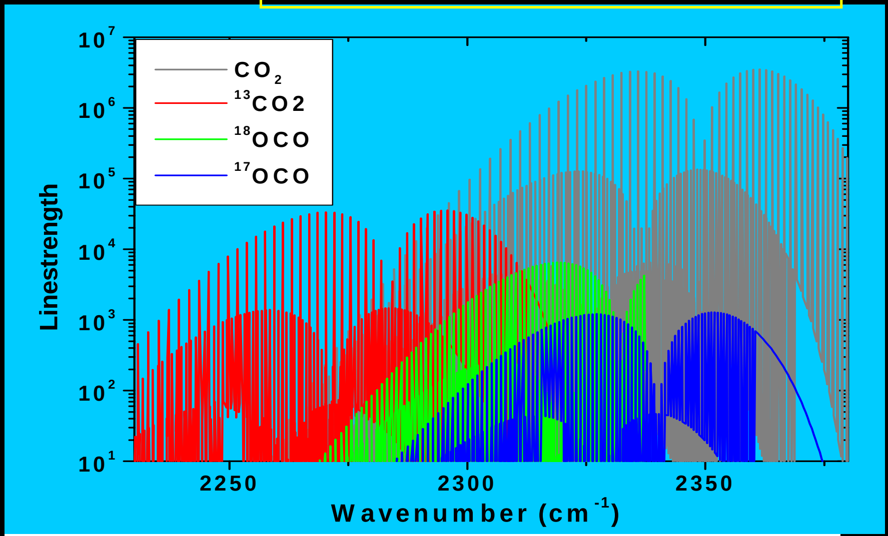
Near-IR and Mid-IR Isotopic CO_2

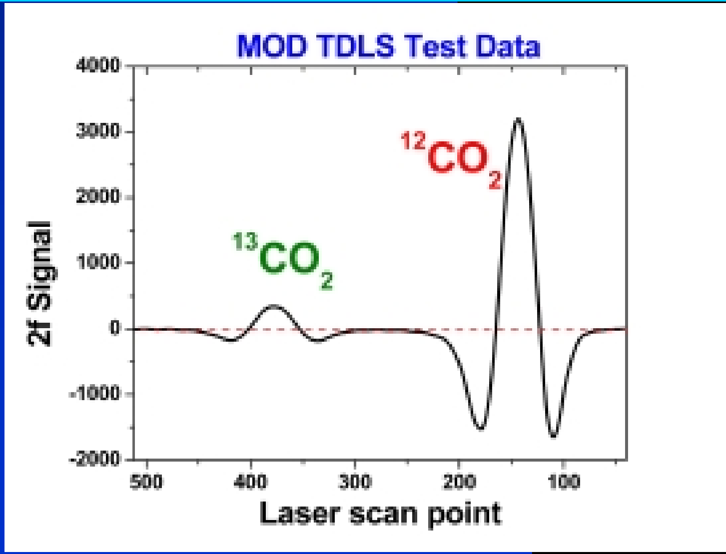
Near-IR 2.05 µm

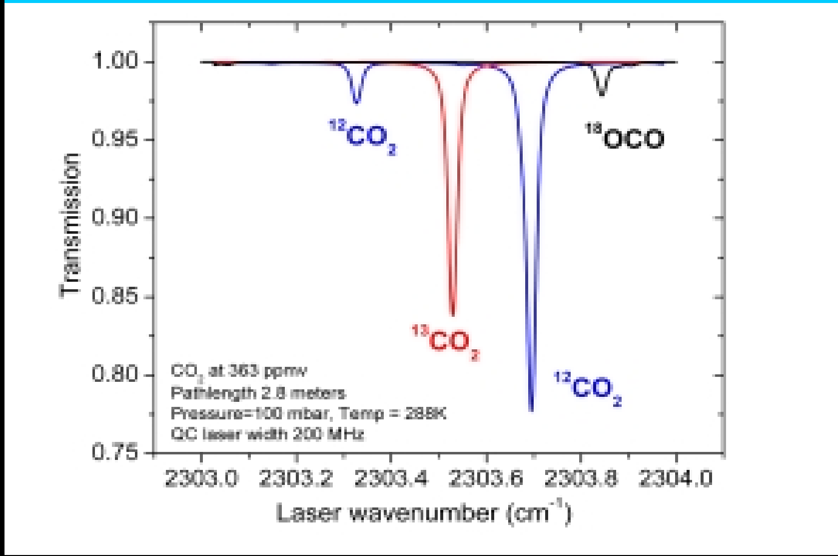
Linestrength→ x 2000

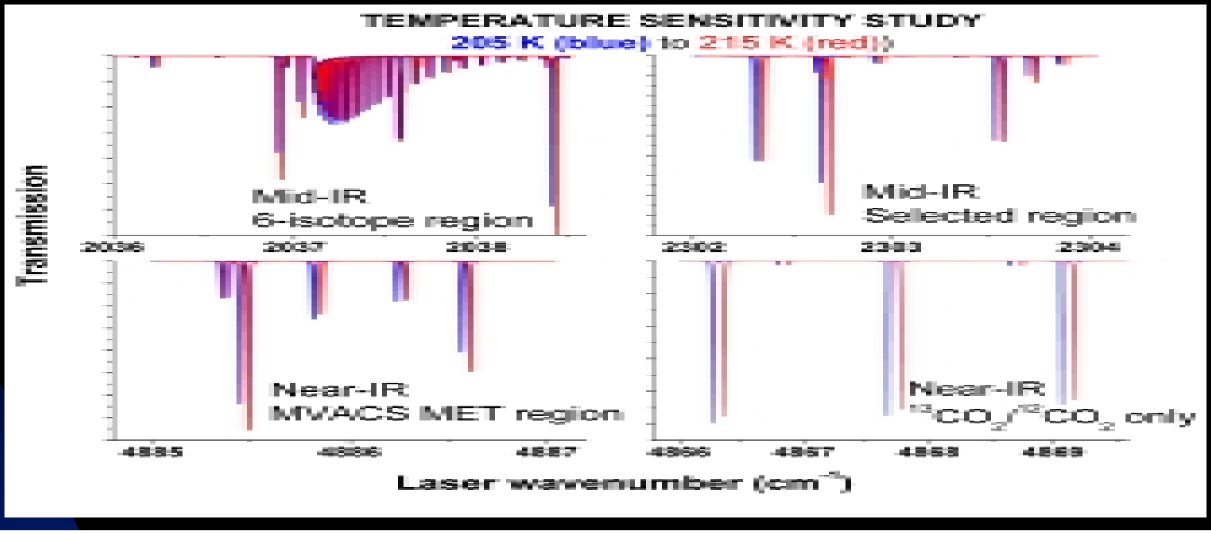
Mid-IR 4.24 µm







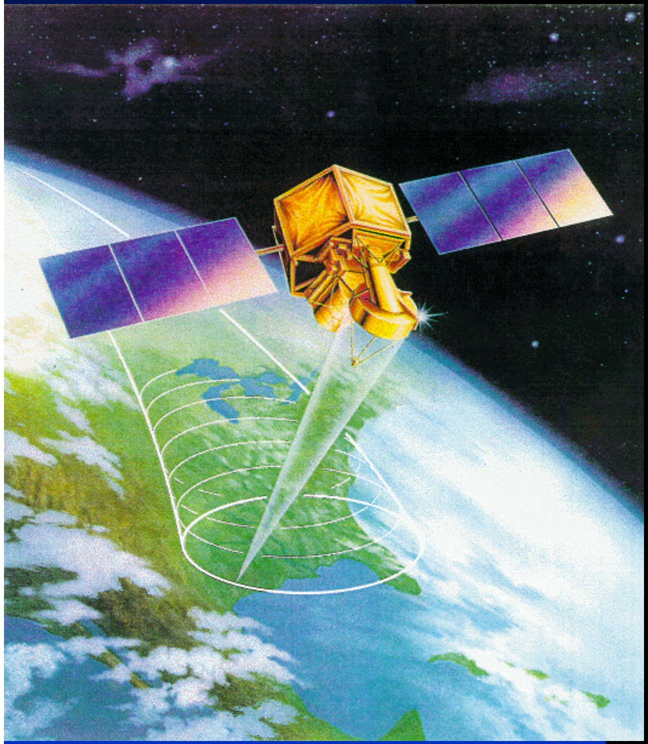




SPECTRAL REGION	$^{13}CO_2/CO_2$	$^{18}OCO/CO_2$
Near-IR MET TDLS **4886 cm^{-1}**	**-24 per mil/deg K**	**+19 per mil/deg K**
Near-IR TEGA TDLS **4876 cm^{-1}**	**-6 per mil/deg K**	**TBD**
Near-IR **4868 cm^{-1}**	**+1 per mil/deg K** **(but dynamic range may limit to 5 per mil total).**	**Not possible**
Mid-IR QCLS strong region at 2302 cm^{-1}	**-2 per mil/deg K**	**-1 per mil/deg K**
Mid-IR QCLS special 6-isotope region at 2037 cm^{-1}	**-1 per mil/deg K, but can fit temp from Q-branch**	**TDB**

Near-IR Laser Absorption Spectrometer for Global CO_2 Mapping

JPL: Robert Menzies (PI), Chris Webster, David Tratt, Gary Spiers
Colorado State Univ.: Graeme Stevens
Coherent Technologies: Mark Philips

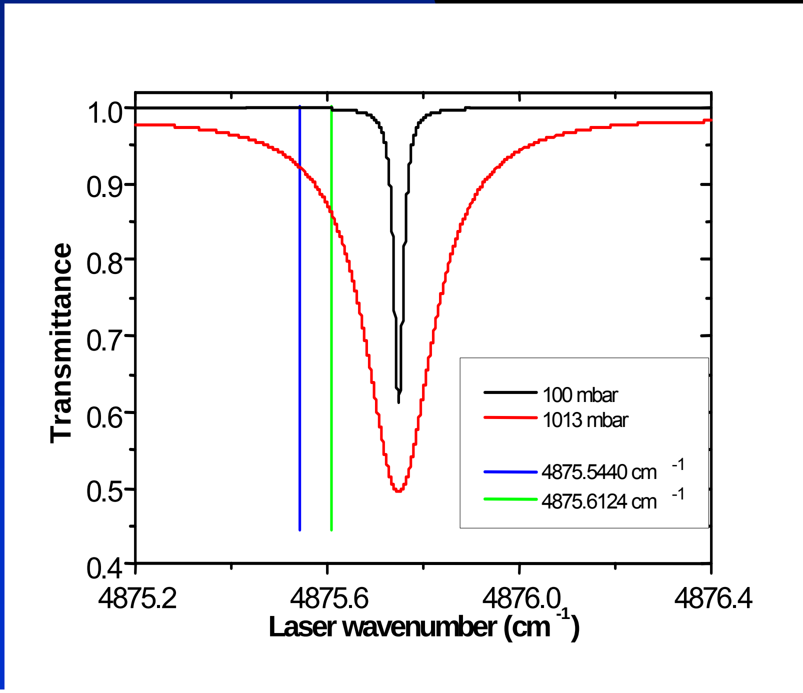


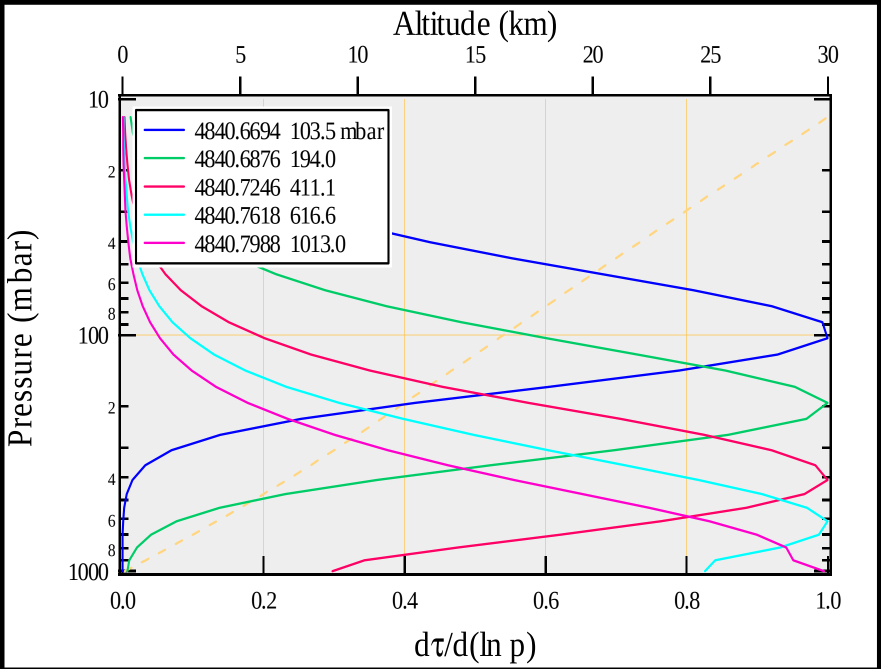
- Near-nadir cw laser (rare-Earth ion doped) illumination of Earth's surface from orbit.
- Analysis of integrated path differential absorption at selected transmit frequencies within CO_2 absorption line region to retrieve tropospheric CO_2 profiles.
- Retrieval of CO_2 profiles in lower and middle troposphere by differential absorption in column above land or ocean backscattering surface.
  - Need column to 1-2 ppmv (0.3%) to define spatial gradients.
  - Code Y IIP funded for DC-8 demonstration (2003).

Near-IR Laser Absorption Spectrometer for Global CO_2 Mapping

- Two near-IR regions suitable for satellite measurements of global CO_2 column
  - 1.57 µm (30012 <- 00001) band

    [Chip Miller, Linda Brown: sharper cores and stronger wings: 2 Voigts reqd.]
  - 2.05 µm (30013 <- 00001) band
- Optimal combination of optical depth, insensitivity to temperature, and no interferences.





Outlook for TDL and QC *in situ* Laser Spectrometers

TDL and QC LAS offer excellent sensitivity, specificity, precision, and response time, especially for small molecules.

• As *in situ* Earth instrument capability has evolved with aircraft missions, laser spectrometers have a more focused niche: H_2O, N_2O, CH_4, CO, HCl, isotopic measurements, H_2CO

- •CO_2 better done with IR absorption (4.3 µm) LiCor NDIR (Wofsy, Sachse, Avallone, etc.): precision 0.01%, accuracy 0.03%.
- • LIF better for radicals OH, NO_2, $ClONO_2$, ClO, Cl_2O_2, etc.
- •CRDS detection has potential for improved precision, but test flight data (CH_4 precision 0.3%) achieved in 10 sec compare to 1.3 sec for conventional LAS.

• *In situ* laser spectrometers for all gases including H_2O will soon be based on mid-IR room temperature cw QC lasers with HgCdTeZn room temperature detectors.

- •For H_2O, enormous flight heritage of Near-IR instruments, and excellent InGaAs detectors will delay transition.

Specific Spectroscopic Measurement Needs – Near-IR

H_2O:

- Immediate need for H_2O in Near-IR 1.37 µm region for 8 existing, flight-tested aircraft and balloon instruments.
- Hitran2000: strong lines targeted by instruments rely on outdated incorrect (?) measurements!
- Linestrengths, FBC, temp dependences, pressure shifts, partition functions.

CO_2:

- Long-term need for Near-IR CO_2 region for global CO_2 LAS measurements. Two near-IR regions suitable for satellite measurements of global CO_2 column
  - 1.57 µm (30012 <- 00001) band
  - 2.05 µm (30013 <- 00001) band
- All parameters important, including line shifts.

Water isotopes H_2O, HDO, $H_2{}^{18}O$ at 2.7 µm better measured in mid-IR.

CH_4 : better measured in mid-IR.

Specific Spectroscopic Measurement Needs – Mid-IR

- Tracer gases N_2O, CH_4, CO
  - Better Lorentz broadening coefficients and temp dependence for CH_4 (ν_3), N_2O (ν_3), and CO fundamental, better partition functions for temp corrections.
- Reactive gases HCl, NO_2, H_2CO, etc
  - HCl well-measured
  - Linestrengths and broadening coefficients needed for H_2CO at 1740 cm-1 (Zahniser/Brown?)
- Isotopic species:
  - Water isotopes
  - CO_2 isotopes
  - CH_4 isotopes, N_2O isotopes, CO isotopes